

*SIGN- VERSUS GOAL-TRACKING: EFFECTS OF
CONDITIONED-STIMULUS-TO-UNCONDITIONED-STIMULUS
DISTANCE*

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Three pigeons were exposed sequentially across experimental phases to five different distances between the conditioned stimulus and the site of the unconditioned stimulus in a sign-/goal-tracking procedure. A computer-controlled tracking system provided a continuous record of the bird's position by continuously monitoring the location of the bird's head in three-dimensional space. It was found that birds sign-tracked (i.e., approached the conditioned stimulus) when the conditioned stimulus was closest to the site of the unconditioned stimulus, goal-tracked (i.e., approached the site of the unconditioned stimulus in the presence of the conditioned stimulus) when the conditioned stimulus was farthest from the site of the unconditioned stimulus, and engaged in both sign- and goal-tracking (or something intermediate) at intermediate conditioned-stimulus-to-unconditioned-stimulus distances. When both sign- and goal-tracking occurred, the former tended to occur in the first half and the latter in the second half of the interval in which the conditioned stimulus was present. The results suggest (a) whether sign- or goal-tracking (or both) occurs is a function of the distance of the conditioned stimulus from the site of the unconditioned stimulus, (b) the fact that pigeons but not rats have been found to sign-track consistently throughout the duration of the conditioned stimulus may be due to quantitatively rather than qualitatively different effects of conditioned-stimulus-to-unconditioned-stimulus distance across species (i.e., a "short" conditioned-stimulus-to-unconditioned-stimulus distance for a pigeon may be a "long" one for a rat), and (c) sign- and goal-tracking may be competing behavioral tendencies that can (e.g., at intermediate conditioned-stimulus-to-unconditioned-stimulus distances) cancel each other out. The findings lend support to theories that specify an interaction between phylogenetic and reinforcement variables in determining whether sign- or goal-tracking will occur in any given experimental preparation.

Key words: sign-tracking, goal-tracking, conditioned-stimulus-to-unconditioned-stimulus distance, autoshaping, generalized matching equation, movement patterns, pigeons

A conditioned stimulus (CS) based on an appetitive unconditioned stimulus (US) typically evokes either approach to the CS or approach to the site of the US. The former effect is termed *sign-tracking* (Hearst & Jenkins, 1974), and the latter is termed *goal-tracking* (Boakes, 1977). Two phenomena that are related to sign- and goal-tracking are *autoshaping* and *automaintenance*. In this report we consider these two phenomena to be specialized cases of sign-tracking in which contact is made with the CS, and focus on

what we here consider to be the more general issue of sign- and goal-tracking (i.e., approaches to the CS or the site of the US are of interest regardless of whether contact with these stimuli occurs).

Most of the research on sign- and goal-tracking has been conducted using pigeons or rats as subjects, with the CS often being an illuminated disk (i.e., keylight) for pigeons and a retractable lever or a light for rats and the US being food for both species. The typical findings have been that pigeons sign-track throughout the CS interval (i.e., the period during which the CS is presented) whereas rats sign-track during the early portion of the CS interval and goal-track during the latter portion (Davey & Cleland, 1982; Davey, Oakley, & Cleland, 1981). Farwell and Ayres (1979) suggested that the difference between rats and pigeons with respect to sign- and goal-tracking may be due to procedural rather than species differences—in other words, pigeons would show sign- and goal-tracking

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behavior more similar to that of rats if the procedures used with pigeons were more similar to those used with rats.

Holland (1980) found that localized CSs nearer the site of the US evoked more sign-tracking and less goal-tracking by rats than did localized CSs farther from the site of the US. Similarly, Boakes (1977) reported goal-tracking by pigeons when the distance between the CS and the site of the US was increased beyond a certain point. This contrasts with Jenkins' finding (described briefly by Hearst & Jenkins, 1974) that pigeons sign-tracked even when the CS-US distance was so great that the birds frequently did not make it to the feeder in time to consume the food that was available for only a few seconds. Both Boakes' and Jenkins' reports contained few procedural details and did not present the data in quantitative form. Peden, Browne, and Hearst (1977) found that pigeons continued sign-tracking a distant visual CS despite a food-omission contingency for doing so; however, as Holland (1980, p. 87) pointed out, the crudeness of the measures used in their study made it difficult to identify approaches to the CS and approaches to the site of the US accurately. Van Hest, van Haaren, Kop, and van der Schoot (1986) also reported sign-tracking in pigeons when the CS-US distance was large. However, the pigeons in their study, unlike those in the studies of Jenkins and Peden *et al.*, did not sacrifice any food by approaching the CS because the brief time limit on the availability of food began only when the birds were close to the feeder.

Because there have been few studies on the relationship between CS-US distance and the occurrence of sign- and goal-tracking in pigeons, and fewer yet that have reported unambiguous quantitative data in either numerical or graphical form, the present study was undertaken to provide detailed quantitative data on this relationship. We used an apparatus that tracked the position of the animal continuously (Eldridge & Pear, 1987; Eldridge, Pear, Torgrud, & Evers, 1988; Pear, 1985; Pear & Eldridge, 1984; Pear & Legris, 1987). This tracking apparatus enabled us to record approaches of varying degrees of closeness to the CS and to the site of the US over the entire CS interval, as opposed to the more commonly used discrete measures

of approach (e.g., stepping on a platform or breaking a photocell beam in front of the CS or the feeder). To allow movement in both horizontal spatial dimensions, we used a chamber with a square floor rather than the long narrow chamber ("long box") used by Jenkins (see Hearst & Jenkins, 1974) and van Hest *et al.* (1986). Our chamber thus was more similar to standard rat and pigeon chambers, such as those used by Holland (1980) and Boakes (1977).

METHOD

Subjects

One adult male Silver King pigeon (Bird 1) that had previously been exposed to various operant reinforcement schedules (variable interval [VI], variable time, fixed ratio, and multiple VI VI) and 2 adult male White King pigeons (Birds 2 and 3) previously used in an autoshaping experiment were maintained at approximately 80% of their free-feeding weights throughout the experiment. When not in an experimental session, the birds were housed in individual cages in a colony room regulated by a 13:11 hr light/dark cycle. The pigeons' diet consisted of commercially available poultry food. Water was available at all times in their home cages, and grit was provided with the food.

Apparatus

The experimental chamber and the programming and recording equipment were located in separate rooms. The room containing the chamber was illuminated by four banks of fluorescent lights in open light fixtures on the ceiling. The lights were wired through a relay that was controlled by the programming equipment, ensuring that the room lights were on during experimental sessions and off when the session concluded. A register in the ceiling ventilated the room. A speaker in the room provided 82-dB white noise as a masking stimulus.

A metal frame painted white supported the top and sides of the experimental chamber (inside dimensions of 57 cm by 57 cm by 38 cm). An aluminum panel and two pieces of white opaque Plexiglas, each of which was attached to one side of the panel, formed the front wall of the chamber. The left adjacent wall consisted of white opaque Plexiglas, and

the other two walls consisted of clear glass. The top of the chamber consisted of two pieces of clear Plexiglas, attached by hinges to facilitate opening the chamber. The floor was aluminum mesh fitted into a stainless steel drop pan. Air spaces in the top and bottom of the chamber provided ventilation. The room lights illuminated the chamber through the top and two clear glass sides.

An aperture for presenting a food hopper was located on the aluminum panel of the front wall, 13.5 cm from the floor and equidistant from the side walls. A white paper shield on the front wall covered a plastic response key that was nonfunctional in this study. A red light (4 cm diameter) that was projected from behind the white Plexiglas of either the front or left side wall by a 100-W General Electric flood lamp served as the CS. A blue light (4 cm diameter) projected 4 cm to the right of the center of the CS served as an intertrial stimulus (ITS). Constituting a differential stimulus during the intertrial interval (ITI), the ITS provided a more sensitive test of the effect of CS-US distance on intertrial behavior than might have been the case had no differential stimulus been used during the ITI. The CS and the ITS could not be presented at the same location because each was projected from a different lamp. Both the CS and the ITS were located 25 cm from the mesh floor of the chamber. The food aperture was illuminated continuously by two SL-313 bulbs in series with a 33-ohm resistor. During food presentation, which consisted of 3-s access to the food hopper filled with the same food used in the home cages, the brightness of this light was intensified by isolation of the resistor from the circuit.

The experimental room also contained two perpendicularly oriented TV cameras directed toward the two clear glass walls of the chamber. The cameras were connected to an electronic video-acquisition module that computed the position of the highest dark region viewed by the cameras. One horizontal coordinate (x) was computed on one camera, and the other horizontal and the vertical coordinates (y , z) were computed on the other. These computations were made 30 times per second. The chamber was turned at an angle of 10° to the cameras to avoid interference of the tracking system by the metal joints connecting

the glass walls. This resulted in the exclusion of several narrow slices of the periphery of the chamber from view of the cameras.

The video-acquisition module was connected to a Cromemco Z-2D® microcomputer that collected data, averaged the values in groups of three (yielding 10 data points per second), stored the averaged data on magnetic disks for later graphing and analysis, and controlled the experiment. An Epson® dot matrix printer, controlled by the computer, was used to plot the data. A block diagram of the apparatus is shown in Pear and Eldridge (1984).

Procedure

General experimental procedures. Experimental sessions were conducted at the same time daily, 5 days per week. Each session terminated after 25 trials (CS-US presentations) or 1,800 s, whichever occurred first. After each bird's session the bird was fed the amount necessary to maintain its weight at approximately 80% of its free-feeding weight.

Experimental design. All birds were exposed to fixed-trial signaled response-independent presentations of food in which the CS and the ITS were projected through either the front or the left wall. The CS was presented for a fixed period of 8 s, at the end of which it terminated and food was presented for 3 s. Presentations of the CS were separated by ITIs ranging from 30 to 90 s, with a mean of 60 s. The lengths of the ITIs were determined by a pseudorandom probability generator. Bird 1 was exposed to the following order of CS distances from the center of the food aperture: (a) 60 cm (CS on the left wall, 51.3 cm from the left front corner), (b) 22 cm (CS on the front wall, 50.5 cm from the left front corner), (c) 60 cm, (d) 22 cm, (e) 26 cm (CS on the front wall, 2.5 cm from the left front corner), (f) 29 cm (CS on the left wall, 2.7 cm from the left front corner), (g) 42 cm (CS on the left wall, 28.2 cm from the left front corner), (h) 60 cm, and (i) 22 cm. Birds 2 and 3 went through the same sequence beginning at (b) instead of (a). The number of sessions each bird received at each CS-US distance is shown in Table 1. Computer-generated plots of the data were analyzed by visual inspection. The birds were shifted from one distance to another when

Table 1

Number of sessions each bird received in each phase.

CS-US distance (cm)	Bird 1	Bird 2	Bird 3
60	12	—	—
22	8	9	7
60	6	9	7
22	4	7	5
26	8	7	6
29	6	5	4
42	4	7	6
60	4	5	5
22	7	4	6

all dependent measures appeared stable and showed little variability.

RESULTS

Figure 1 shows the mean distance of each bird's head from the CS and from the ITS across sessions. Note that the animals' mean distances from the CS were consistently shorter than their mean distances from the ITS across all CS-US distances, except for Bird 1 at the greatest distance (60 cm). Thus, it appears that the CS exerted differential control over the behavior of all 3 birds. In addition, note that there was no evidence of an order effect; in particular, increasing the CS-US distances gradually did not appear to result in closer approach to the CS when it was far from the site of the US.

Although Figure 1 shows that the position of the birds relative to the CS and the ITS varied as a function of the distance between these stimuli and the site of the US, it provides little information about the movements of the birds with respect to these two stimuli as a function of CS-US distance. The following figures present more detailed information regarding the specific movements of the birds with respect to the CS and the ITS. Figure 2 shows the movements of each bird, plotted as paths in the xy plane from the top view, during the 5th, 12th, and 20th CS presentations of the last session of phases in which the CS was closest to the food aperture (CS-US distance = 22 cm) and farthest from the food aperture (CS-US distance = 60 cm). These particular CS presentations were chosen arbitrarily to ensure the representativeness of the movement patterns shown; visual in-

spection indicated that they were representative of those that occurred during each phase. The phases are shown in the order in which they were presented beginning at the top of the figure, with the extra phase Bird 1 received at the beginning of the experiment at the largest CS-US distance omitted from the figure.

Note that when the CS-US distance was 22 cm, all birds approached the CS at the beginning of the CS interval and engaged in back-and-forth movements close to it until food was delivered. Moreover, all birds were consistently closer to the CS at the end than at the beginning of the CS interval. During the exposures to the 60-cm CS-US distance, all birds approached the food aperture when the CS was presented and remained there, occasionally standing still and at other times bobbing their heads around the food aperture until food was delivered. Moreover, all birds were consistently closer to the food aperture at the end than at the beginning of the CS interval. Thus, Figure 2 indicates that the reason the birds were closer to the CS when the CS-US distance was 22 cm than when it was 60 cm, as seen in Figure 1, was because the birds sign-tracked in the former case and goal-tracked in the latter case.

Figure 3 shows the movements of each bird, plotted as a path in the xy plane, that occurred during the ITI prior to each CS presentation shown in Figure 2. These movement patterns are representative of those that occurred during other ITIs at CS-US distances of 22 cm and 60 cm. In general, CS-US distance appeared to have little or no effect on the movement patterns during the ITI. Bird 1 initially paced along the right wall during the ITI, but then later began clockwise circling and continued engaging in this pattern for the remainder of the experiment regardless of CS-US distance. Movement patterns of Birds 2 and 3 during the ITI throughout all phases consisted mainly of pacing along the front wall, with Bird 2 sometimes also moving along the right wall. Thus, the increase in the birds' mean distance from the ITS as the CS and the ITS were moved farther from the site of the US (Figure 1) reflected the fact that the birds engaged in behavior close to the food aperture during the ITS regardless of the positions of the CS and the ITS. Comparison of Figure 2 with Figure 3 reveals

DISTANCE FROM CS AND ITS (cm)

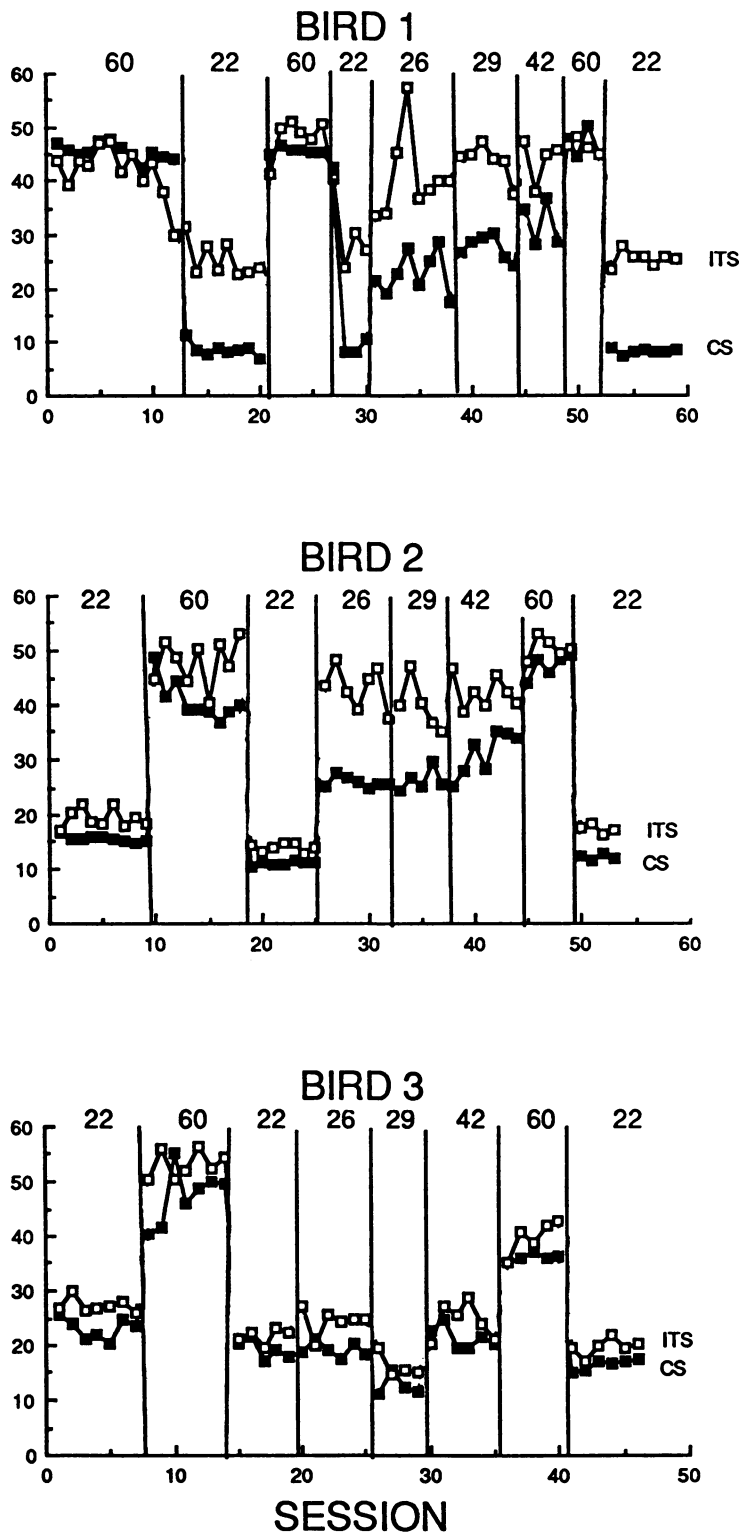


Fig. 1. Mean distance from the CS (■) and the ITS (□) across all sessions for all birds.

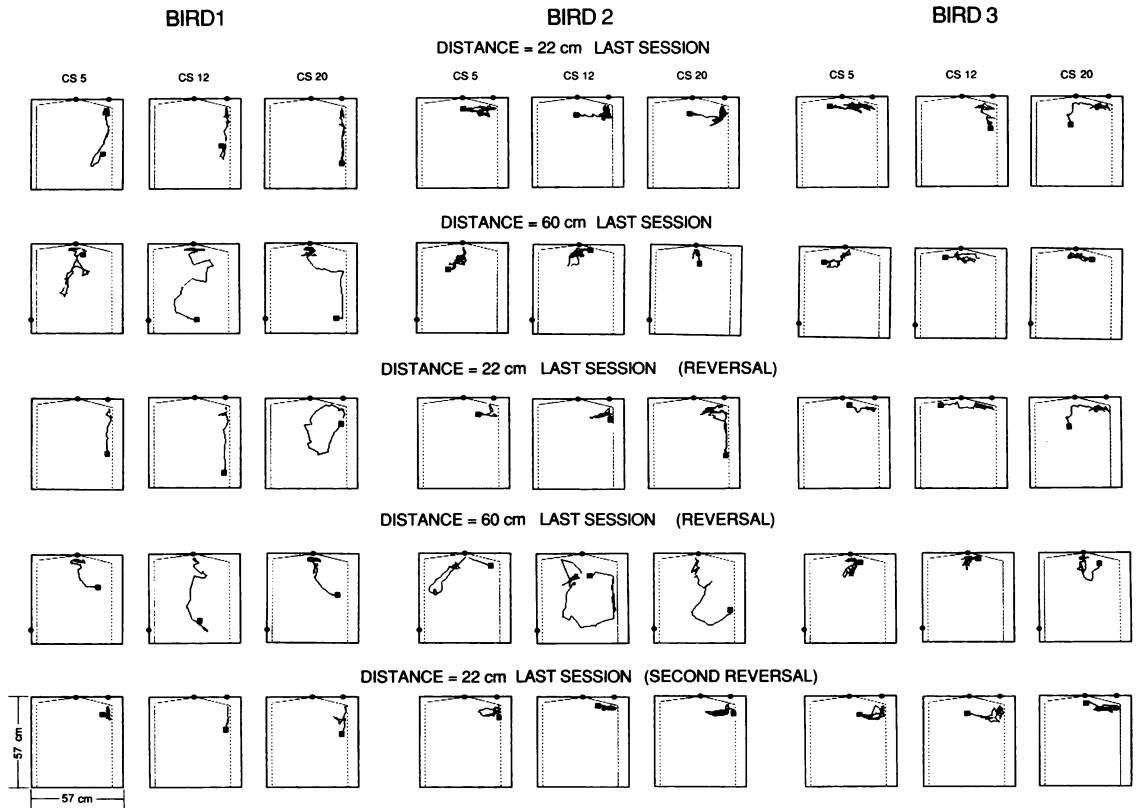


Fig. 2. Paths of each bird during the 5th, 12th, and 20th CS presentations on the last sessions of phases in which the CS was located 22 cm and 60 cm from the feeder, plotted from a top view perspective of the xy plane. The phases are shown in the order in which they were presented beginning at the top of the figure, with the phase Bird 1 received at the CS-US distance of 60 cm at the beginning of the experiment omitted. The position of the feeder is indicated by the dot at the top center of each plot. The position of the CS is indicated by the other dot (at the top right for the 22-cm distance and on the lower left for the 60-cm distance). The dashed lines indicate regions of the chamber from which data could not be obtained for the technical reason explained in the apparatus section. The black square in each plot indicates the position of the bird at the beginning of the CS presentation.

that the birds were not consistently closer to the food aperture or the CS at the end of the ITI (indicated by the black square in each plot in Figure 2, because the bird's position at the end of the ITI was the same as its position at the beginning of the CS interval) than at other times during the ITI. Thus, the ITS did not control approach to the CS or the site of the US, although as indicated above, the CS did.

Figure 4 shows the movement patterns of each bird plotted both as distance from the CS over time and as paths in the xy plane during the 12th and 13th CS presentations of the last session of each of the intermediate CS-US distances (i.e., CS-US distances = 26 cm, 29 cm, and 42 cm). These particular

CS presentations were chosen arbitrarily to ensure that the movement patterns would be representative; visual inspection indicated that they were representative of those that occurred during other CS presentations at the intermediate CS-US distances. Note that as the CS-US distance increased within the intermediate distances, the birds tended to move less close to the CS and/or to remain close to it for shorter periods of time. For example, in the samples shown at the 26-cm distance, Bird 1 approached the CS at the beginning of the CS interval and remained near it until food was delivered. As the distance between the CS and the site of the US increased, the distance that this bird remained from the CS tended to increase. At the 26-cm distance,

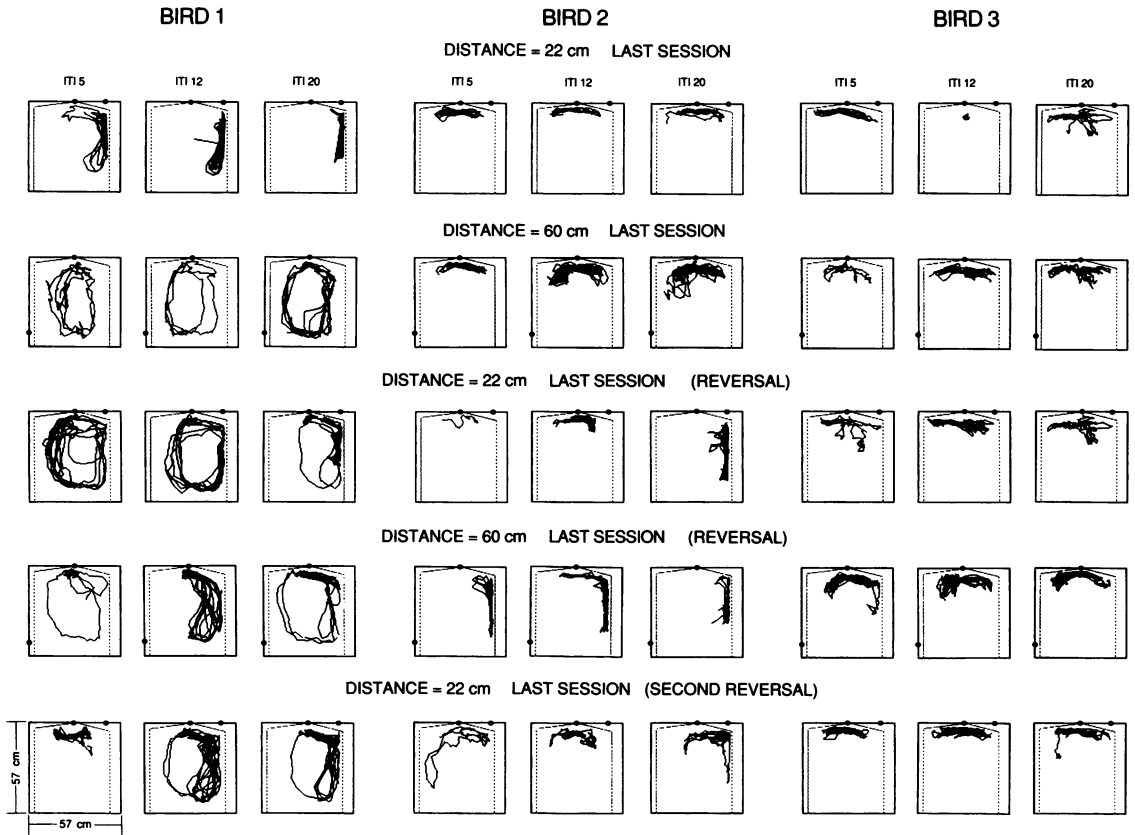


Fig. 3. Paths of each bird during the ITIs prior to the CS presentations shown in Figure 2. The explanation of the plots is the same as for Figure 2 (except beginning and ending positions are not indicated).

Birds 2 and 3 approached the CS at the beginning of the CS interval and remained near it until food was delivered; but at the 29-cm and 42-cm CS-US distances, these birds approached the CS at the beginning of the CS interval and began moving away from it before food was delivered. Thus, the increase in the birds' distances from the CS as the CS-US distance increased, as seen in Figure 1, was the result of the birds (a) not moving in as close to the CS during longer CS-US distances as they did during shorter CS-US distances and/or (b) withdrawing from the immediate vicinity of the CS before its termination. In general, when the birds withdrew from the CS before its termination, they moved in the direction of the site of the US. Thus, the intermediate CS-US distances appeared to produce either a mixture of sign-tracking and goal-tracking or something intermediate between the two. Figure 4 shows that the CS did not control approach

either to the CS or to the food aperture at the intermediate CS-US distances as consistently as it did at the two extreme CS-US distances. This finding, taken in the context of the control shown at the extreme CS-US distances, points to the possibility of competing behavioral tendencies.

Although prior exposure to the short and intermediate CS-US distances before exposure to the largest CS-US distance had no apparent long-term effect on approach to the CS when it was far from the site of the US (Figure 1), prior exposure did appear to have a short-term or transitional effect. That is, there was some tendency to approach the far CS after exposure to the short and intermediate CS-US distances that was not present when the far CS was presented before exposure to the short and intermediate CS-US distances. To illustrate the transition in the movement patterns from sign-tracking to goal-tracking at the largest CS-US distance after

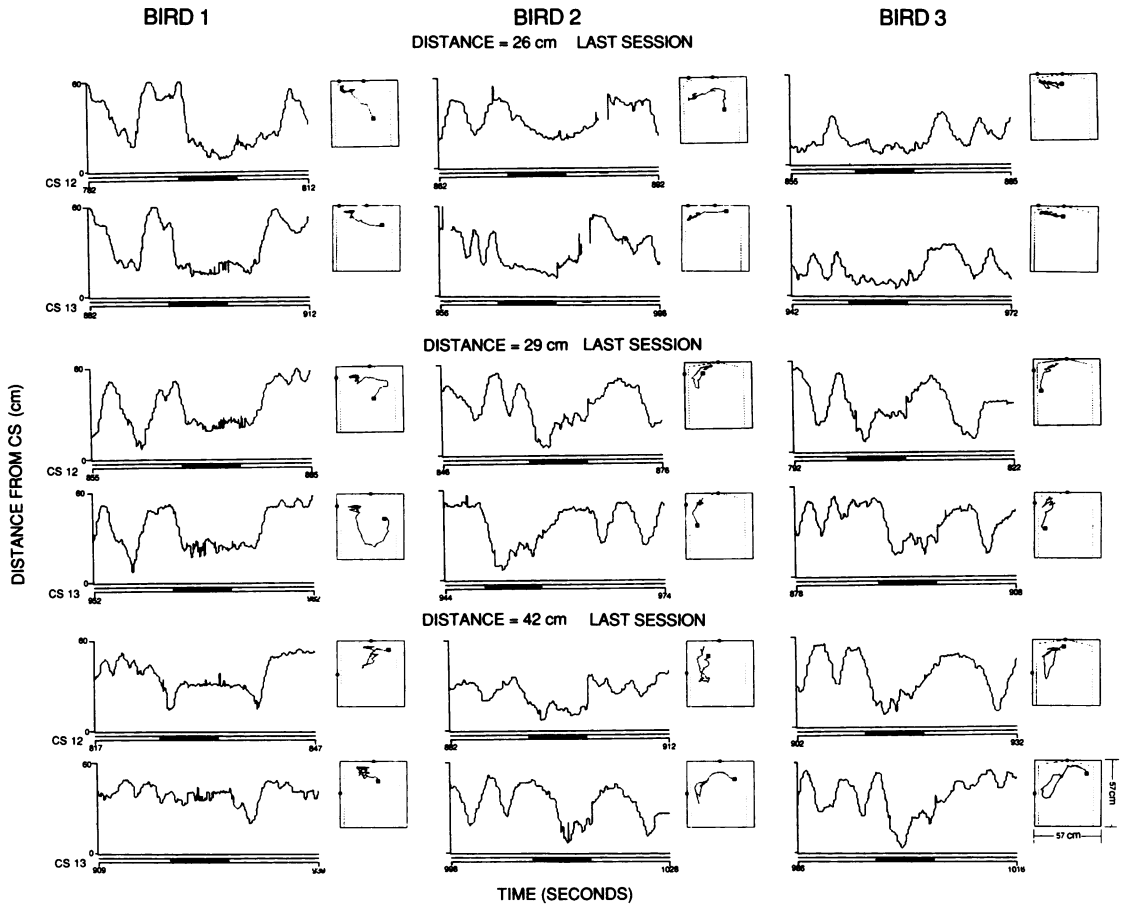


Fig. 4. Distance from the CS over time (left plots) for each bird and paths (right plots) produced by each bird during the 12th and 13th CS presentations on the last sessions of phases in which the CS was located 26 cm, 29 cm, and 42 cm from the feeder. The top plots for each CS-US distance are for the 12th CS presentation, and the bottom plots are for the 13th CS presentation. The solid bar in the band at the bottom of each distance-versus-time plot indicates the CS presentation. The marks in the upper part of the band at the 26-cm distance for Bird 2 indicate instances in which the bird's head was not in view of both cameras, probably due to wing flapping. The explanation of the plots of the paths is the same as for Figure 2.

exposure to the short and intermediate CS-US distances, the next three figures show the birds' movements, as paths in the *xy* plane, during all CSs of the first session of the 60-cm CS-US distance following exposure to the short and intermediate CS-US distances. Figure 5 shows Bird 1's transition from sign-tracking to goal-tracking. Note that this bird moved toward the CS during its 1st, 3rd, 4th, 6th, 7th, 10th, and 11th presentations. Probably because of this, as indicated by visual observation of the session as well as the plots in the figure, the bird did not reach the food aperture in time to receive all (or, in some cases, even part) of the food

that was available during the food interval (i.e., the period during which the food hopper was presented) following those CS presentations. On all of the last 10 presentations, Bird 1 approached the food aperture at the beginning of the CS interval and ate throughout the food interval. Figure 6 shows Bird 2's transition from sign-tracking to goal-tracking. This bird remained stationary during the first four CSs. During the 5th, 7th, 9th, 10th, 11th, 14th, 15th, 17th, 21st, 22nd, and 23rd CS presentations, Bird 2 initially approached the CS but later moved toward the site of the US. On 8 of the last 10 presentations, Bird

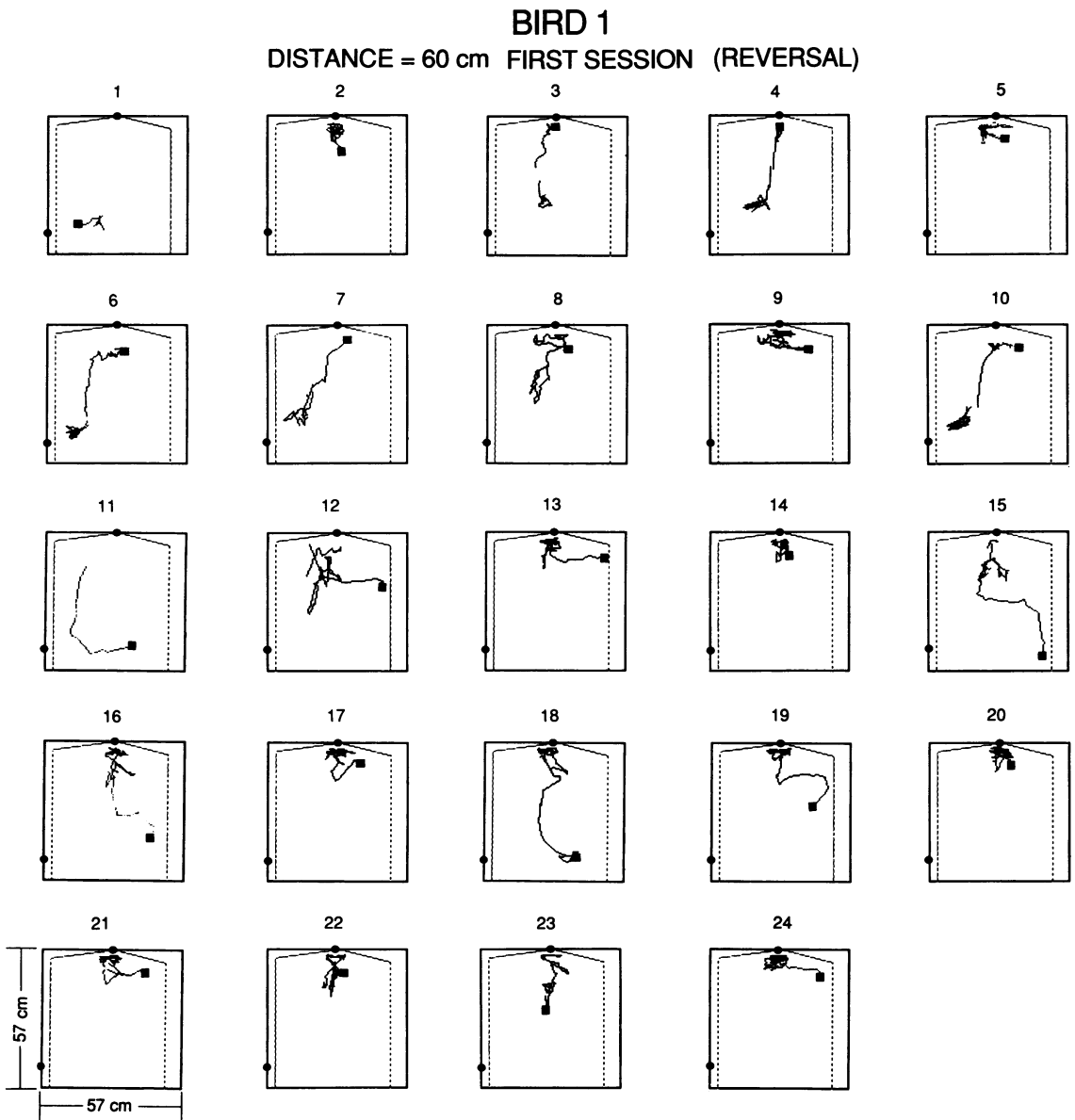


Fig. 5. Paths of Bird 1 during all 24 CSs, numbered consecutively, of the first session of the third exposure to the 60-cm distance between the CS and the feeder (after exposure to the intermediate distances). The explanation of the plots is the same as for Figure 2.

2 approached the food aperture and ate throughout the food interval. The eighth CS presentation was the only clear instance in which approaching the CS prevented this bird from obtaining food.

Figure 7 shows Bird 3's transition from sign-tracking to goal-tracking. This bird generally approached the site of the US at the beginning of the CS interval and remained

there until food was delivered at the end of the CS interval. During the 4th, 9th, 10th, 18th, and 19th CS presentations, Bird 3 initially approached the CS but later moved toward the site of the US. On 8 of the last 10 presentations, Bird 3 approached the food aperture at the beginning of the CS interval and ate throughout the food interval. The 1st and 14th CS presentations were the only

BIRD 2
DISTANCE = 60 cm FIRST SESSION (REVERSAL)

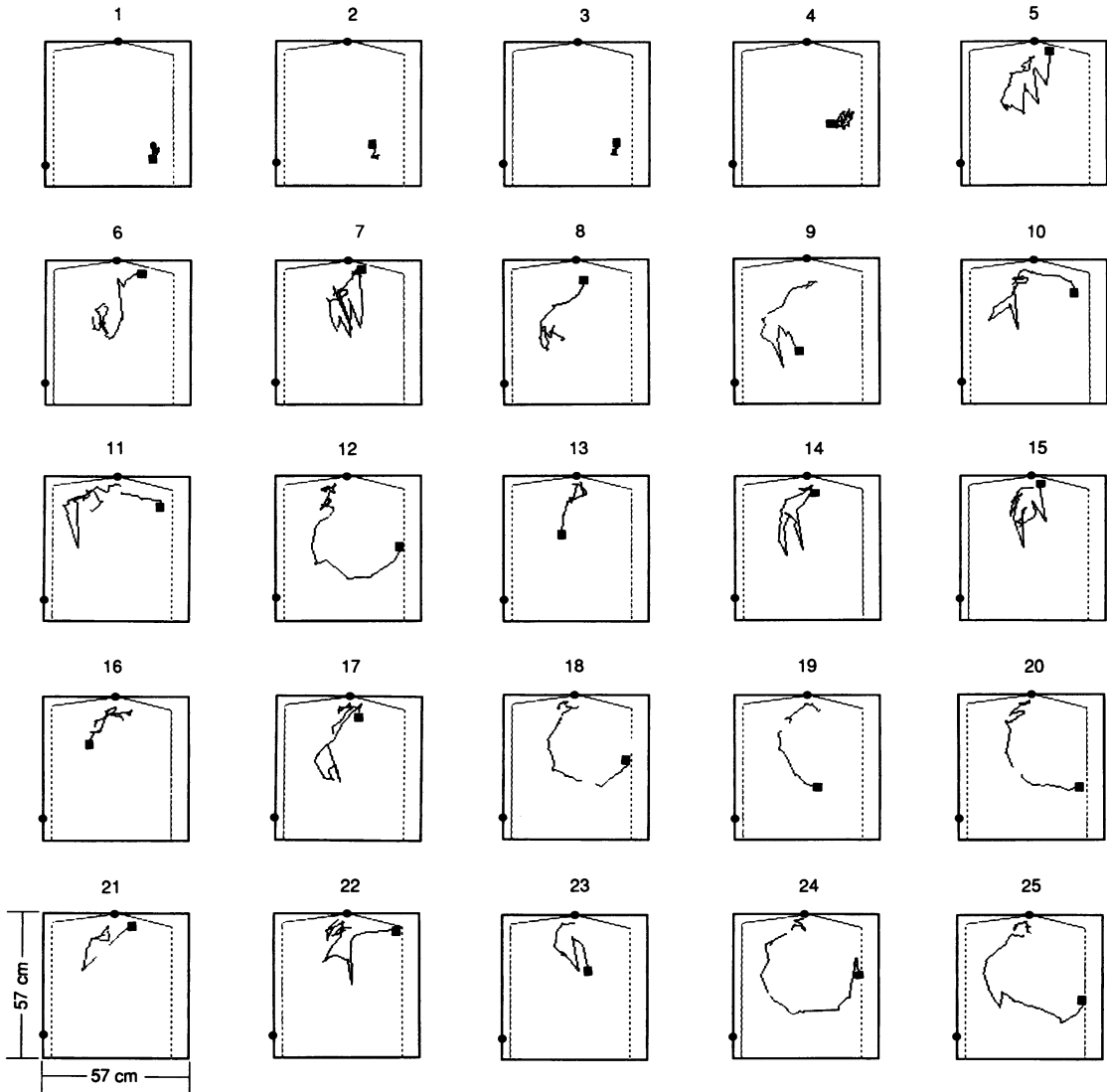


Fig. 6. Paths of Bird 2 during all 25 CSs, numbered consecutively, of the first session of the second exposure to the 60-cm distance between the CS and the feeder (after exposure to the intermediate distances). The explanation of the plots is the same as for Figure 2.

clear instances in which approaching the CS prevented this bird from obtaining food.

Thus, Figures 5, 6, and 7 show that the birds consistently goal-tracked after sign-tracking on the initial CS presentations at the longest CS-US distance after exposure to the short and intermediate CS-US distances. On the last 10 trials, Bird 1 approached the site of the US 10 of 10 times when the

CS was presented, and Birds 2 and 3 each approached the food aperture 8 of 10 times when the CS was presented. Given that the birds could have gone anywhere during the CS, the fact that they consistently approached the food aperture during CS presentations indicates that approach to the site of the US was under the control of the CS at the longest CS-US distance.

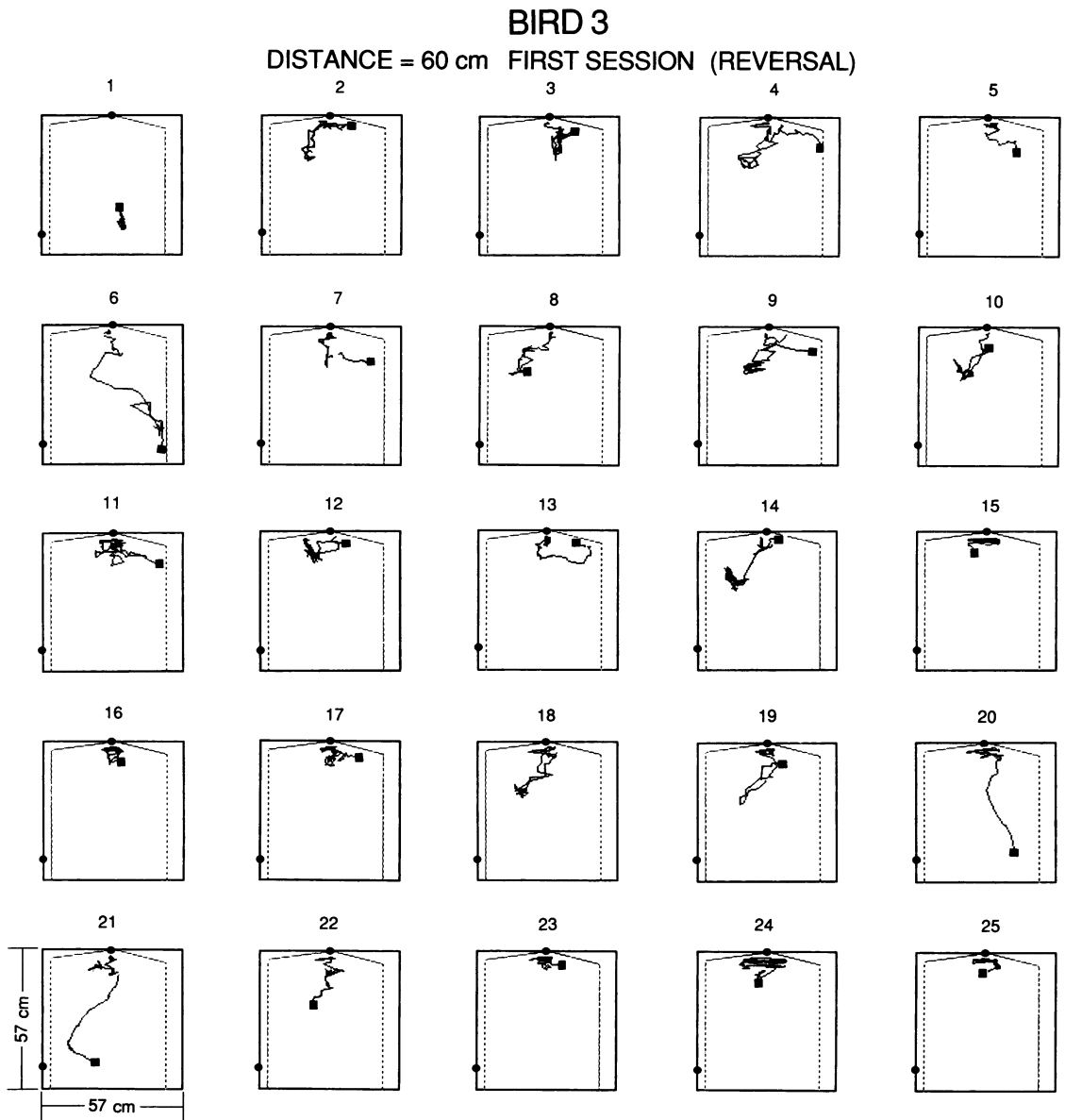


Fig. 7. Paths of Bird 3 during all 25 CSs, numbered consecutively, of the first session of the second exposure to the 60-cm distance between the CS and the feeder (after exposure to the intermediate distances). The explanation of the plots is the same as for Figure 2.

DISCUSSION

This study provided quantitative support of Boakes' (1977) observation that pigeons goal-track at large CS-US distances. When the distance between the CS and the site of the US in the present study was 22 cm, all 3 birds consistently sign-tracked; when the distance was 60 cm, all 3 birds consistently

goal-tracked. Intermediate CS-US distances resulted in a mixture of sign- and goal-tracking or something intermediate between them.

In addition to different distances, different walls were used for the placement of the nearer and farther CSs. Although this use of different walls may have affected the results, they cannot be solely responsible for the differential

effects obtained because differences were obtained between the two CS locations on the left wall. It is unlikely that the effects obtained in this study depended in any significant way on the birds' preexperimental histories, because those histories were not the same for all 3 birds. The generality of the present findings is also supported by the fact that they are consistent with data obtained with rats. Thus, the present study demonstrated that there are conditions under which pigeons yield results similar to those obtained with rats, in which sign-tracking occurs near the beginning of the CS interval and goal-tracking near the end (Davey & Cleland, 1984; Davey, Cleland, & Oakley, 1982) and goal-tracking increases as the distance between the CS and the site of the US is increased (Holland, 1980).

Most theories encompassing sign- and goal-tracking emphasize nonoperant aspects of these behavioral categories (e.g., Boakes, 1979; Cleland & Davey, 1983; Davey & Cleland, 1984; Holland, 1979, 1980; Timberlake & Lucas, 1989). Indeed, there is considerable evidence that these behavioral categories are not as readily affected by their consequences, as some operant accounts would seem to imply should be the case, if they are to be considered operant (see Pear & Eldridge, 1984). For example, some researchers have observed that sign-tracking persists even when opposed by strong reinforcement contingencies (e.g., Williams & Williams, 1969) and that the form of the sign-tracking response (i.e., the manner in which the animal approaches and interacts with the CS) can be strongly influenced by factors that are almost certainly of phylogenetic origin (e.g., Timberlake & Grant, 1975). Nevertheless, studies also show that sign-tracking (in pigeon and rats) and goal-tracking (at least in rats) is modifiable to some extent by its consequences (e.g., Barrera, 1974; Eldridge & Pear, 1987; Holland, 1979). Most sign-/goal-tracking theorists acknowledge an interaction between operant and non-operant processes, but the exact nature of the interaction is usually not specified clearly in the theories. One possibly fruitful way of describing this interaction is through the generalized matching equation (Baum, 1974, 1979).

Although the generalized matching equation was developed to describe behavior maintained by concurrently programmed schedules

of reinforcement, it can be extended readily to situations in which reinforcement is presented independently of behavior (Pear, 1988). If B_i and B_j are the amounts of responding (measured in units of time or response rate) allocated to two behavior classes, it follows from any of several versions of the generalized matching equation that

$$\frac{B_i}{B_j} = (bc^s)^{\frac{1}{1-s}}, \quad (1)$$

where b is a bias (termed *response bias*) toward one of the behavior classes when all reinforcement parameters are equal, c is relative reinforcements per unit of responding in each of the two behavior classes, and s is a constant indexing sensitivity to relative reinforcement rate for the two behavior classes (see Pear, 1988). On the basis of the literature on the generalized matching equation (e.g., Baum, 1979), the value of s is assumed to be close to, but less than, 1. Thus, it can be seen from Equation 1 that if bc^s is much larger than 1 the value of B_i/B_j will be very large (implying almost exclusive preference for alternative i), whereas if bc^s is much smaller than 1 the value of B_i/B_j will be very small (implying almost exclusive preference for alternative j). To use the equation to account for the effect of distance between the CS and the US on sign- versus goal-tracking, it is necessary only to assume that approaching a stimulus that has preceded food (sign-tracking) has a high response bias relative to approaching the location in which food subsequently was presented (goal-tracking), which in turn has a high response bias relative to other activities. Let B_i and B_j represent measures of sign-tracking and goal-tracking, respectively. Because in the sign-/goal-tracking procedure reinforcements are delivered independently of whether the animal approaches the CS or the site of the US, c will be a constant. It can be seen from Equation 1 that as long as b is sufficiently larger than $1/c^s$ sign-tracking (alternative i) will be almost exclusively preferred over goal-tracking (alternative j); however, as the distance between the CS and the US is increased, the time it takes for the animal to travel from the site of the CS to the US increases, causing a loss of reinforcement or an increase in aversiveness (which may have the same effect

as a loss in reinforcement) due to the delay in reinforcement or to the energy involved in traveling to the site of the CS and then to the US. If the CS-US distance is increased sufficiently, a point is reached at which c is sufficiently less than $1/b$ to cause goal-tracking to be almost exclusively preferred. This prediction accords with the data from the present study in which there was virtually exclusive preference for sign-tracking at the smallest CS-US distance (22 cm) and virtually exclusive preference for goal-tracking at the largest CS-US distance (60 cm). It may be assumed that at the intermediate CS-US distances c was close to $1/b$, in which case sign-tracking and goal-tracking should occur about equally, which is essentially what happened.

The above formulation accounts for the fact that goal-tracking increases when sign-tracking results in the omission of reinforcement (Holland, 1979) and for the fact that goal-tracking tends to occur toward the end of the CS interval (see Figure 4; Davey & Cleland, 1982; Davey et al., 1981). Indeed, it is possible that the reason sign-tracking throughout the CS interval has been found more often with pigeons than with rats is also due to an interaction between phylogenetic (e.g., poor distance vision or different feeding strategies for rats relative to pigeons) and reinforcement variables. For example, a CS-US distance that might be small for a pigeon (and hence result in sign-tracking throughout the CS interval) might be large for a rat (and hence result in goal-tracking during the latter portion of the CS interval). If this is correct, a CS that is salient to a rat and very close to the site of the US should evoke sign-tracking in rats throughout the CS interval.

However, the above formulation does not readily account for the fact that Jenkins (see Hearst & Jenkins, 1974) obtained sign-tracking at a larger CS-US distance than the one that produced goal-tracking in the present study, even though the birds in Jenkins' study consequently often failed to obtain some or all of the available food. The generalized matching formulation does plausibly explain why van Hest et al. (1986) found sign-tracking at a comparable CS-US distance. At the end of the CS interval, the pigeons in the study by van Hest et al. had 15 s in which to intersect a photobeam close to the feeder that would

then result in 4-s access to food; thus, approaching the CS when it was far from the feeder resulted in little or no loss of food. Although Boakes' (1977) description of his study is brief, it appears that it, like the present study, did not contain any procedure to prevent food loss due to travel time from the CS.

A number of procedural differences may account for the differences between the findings of Jenkins on the one hand and those of Boakes and the present study on the other, including intensity of the background illumination, saliency of the cues associated with food, duration of the food interval, characteristics of the CS, and shape of the experimental chamber (Boakes, 1979). Speculation about how these and other nonreinforcement variables may have produced different findings in different sign-/goal-tracking studies would be premature because little or nothing is known at present about the effects of these variables on sign-versus goal-tracking. In addition, there are certain behavioral processes, such as stimulus and response generalization, that are probably important in sign- and goal-tracking. Incorporation of these phenomena could help to explain some of the findings that appear to contradict the present formulation. For example, response generalization could account for the fact that animals sometimes continue to sign-track during omission contingencies. Responses that are excluded from reinforcement by the omission contingency may occur due to response generalization from responses that are similar to them but are not excluded from reinforcement (cf. Eldridge & Pear's [1987] demonstration that pigeons make pecking motions close to the key in the presence of a keylight paired with food during a food-omission contingency for key pecking).

The present extension of the generalized matching equation to sign-/goal-tracking raises currently unresolved empirical issues with regard to that equation. One issue is whether the equation is a valid description of behavior under concurrent schedules (see Alsop & Davison, 1991, and Davison & Alsop, 1991, for recent discussion of and data pertaining to this issue). If it is, another issue is the value of s . As seen from Equation 1, $s \geq 1$ causes problems for the present extension. If $s = 1$, Equation 1 is indeterminate. If $s > 1$,

the equation predicts an inverse relation between the behavior ratio and bc , which is contrary to common sense because it implies a tendency to prefer the less biased or the less reinforced activity. Research is needed to determine conditions under which $s \geq 1$ and whether those conditions would pertain to the present extension. This problem is not unique to extensions of the generalized matching equation to situations in which reinforcement is presented independently of behavior; it occurs as well with application of the generalized matching equation to concurrent schedules in which overall reinforcement ratios are directly proportional to overall behavior ratios (e.g., concurrent-ratio schedules and concurrent-interval schedules programmed by the same interval timer, in which each programmed reinforcement is available only once).

It is important to note that the extension here of the generalized matching equation to sign-/goal-tracking is qualitative rather than quantitative (i.e., the equation was not used to make specific quantitative predictions). Nevertheless, the application of the generalized matching formulation to sign-/goal-tracking may prove useful in at least three ways. First, as a mathematical expression, the formulation may provide a convenient shorthand for compactly describing the interaction between phylogenetic and reinforcement variables in sign-/goal-tracking. Second, it identifies parameters that may be critical to that interaction, and this may prove useful in designing studies to investigate the interaction. Third, by conceptually linking two distinct areas (concurrent schedules and sign-/goal-tracking), the formulation may lead to a more parsimonious account of the behavior investigated in both areas than thus far has been available.

Besides providing information about behavior during the CS, the present study also provides information about behavior during the ITI and about the differential control exerted by the CS and the ITS. Behavior during the ITI was stereotyped, as has been found in other studies (e.g., Brandon & Paul, 1987; Eldridge & Pear, 1987; Matthews & Lerer, 1987; Pear & Eldridge, 1984), and the pattern of the stereotyped behavior did not depend in any obvious way on the position of the CS and the ITS or on whether sign-

tracking or goal-tracking occurred. It should be noted that although in this study the movement patterns during the ITI tended to occur along the wall on which the food aperture was located, this is not always the case (Eldridge & Pear, 1987).

REFERENCES

- Alsop, B., & Davison, M. (1991). Effects of varying stimulus disparity and the reinforcer ratio in concurrent-schedule and signal-detection procedures. *Journal of the Experimental Analysis of Behavior*, *56*, 67-80.
- Barrera, F. J. (1974). Centrifugal selection of signal-directed pecking. *Journal of the Experimental Analysis of Behavior*, *22*, 341-355.
- Baum, W. M. (1974). On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior*, *22*, 231-242.
- Baum, W. M. (1979). Matching, undermatching, and overmatching in studies of choice. *Journal of the Experimental Analysis of Behavior*, *32*, 269-281.
- Boakes, R. A. (1977). Performance on learning to associate a stimulus with positive reinforcement. In H. Davis & H. M. B. Hurwitz (Eds.), *Operant-Pavlovian interactions* (pp. 67-101). Hillsdale, NJ: Erlbaum.
- Boakes, R. A. (1979). Interactions between type I and type II processes involving positive reinforcement. In A. Dickinson & R. A. Boakes (Eds.), *Mechanisms of learning and motivation: A memorial volume to Jerzy Konorski* (pp. 233-268). Hillsdale, NJ: Erlbaum.
- Brandon, S. E., & Paul, H. (1987). The effects of activity conditioned in random CS/US training on performance in autoshaping. *Animal Learning & Behavior*, *15*, 263-284.
- Cleland, G. G., & Davey, G. C. L. (1983). Autoshaping in the rat: The effects of localizable visual and auditory signals for food. *Journal of the Experimental Analysis of Behavior*, *40*, 47-56.
- Davey, G. C. L., & Cleland, G. G. (1982). The effect of partial reinforcement on the acquisition and extinction of sign-tracking and goal-tracking in the rat. *Bulletin of the Psychonomic Society*, *19*, 115-118.
- Davey, G. C. L., & Cleland, G. G. (1984). Food anticipation and lever-directed activities in rats. *Learning and Motivation*, *15*, 12-36.
- Davey, G. C. L., Cleland, G. G., & Oakley, D. A. (1982). Applying Konorski's model of classical conditioning to signal-centered behavior in the rat: Some functional similarities between hunger CRs and sign-tracking. *Animal Learning & Behavior*, *10*, 257-262.
- Davey, G. C. L., Oakley, D., & Cleland, G. G. (1981). Autoshaping in the rat: Effects of omission on the form of the response. *Journal of the Experimental Analysis of Behavior*, *36*, 75-91.
- Davison, M., & Alsop, B. (1991). Behavior-dependent reinforcer-rate changes in concurrent schedules: A further analysis. *Journal of the Experimental Analysis of Behavior*, *56*, 1-19.
- Eldridge, G. D., & Pear, J. J. (1987). Topographical variations in behavior during autoshaping, auto-

- maintenance, and omission training. *Journal of the Experimental Analysis of Behavior*, **47**, 319-333.
- Eldridge, G. D., Pear, J. J., Torgrud, L. J., & Evers, B. H. (1988). Effects of prior contingent reinforcement on superstitious behavior. *Animal Learning & Behavior*, **16**, 277-284.
- Farwell, B. J., & Ayres, J. B. (1979). Stimulus-reinforcer and response-reinforcer relations in the control of conditioned appetitive headpoking ("goal tracking") in rats. *Learning and Motivation*, **10**, 295-312.
- Hearst, E., & Jenkins, H. M. (1974). *Sign tracking: The stimulus-reinforcer relation and directed action*. Austin, TX: Psychonomic Society.
- Holland, P. C. (1979). Differential effects of omission contingencies on various components of Pavlovian appetitive conditioned behavior in rats. *Journal of Experimental Psychology: Animal Behavior Processes*, **5**, 178-193.
- Holland, P. C. (1980). Influence of visual conditioned stimulus characteristics on the form of Pavlovian appetitive conditioned responding in rats. *Journal of Experimental Psychology: Animal Behavior Processes*, **6**, 81-97.
- Matthews, T. J., & Lerer, B. E. (1987). Behavior patterns in pigeons during autoshaping with an incremental conditioned stimulus. *Animal Learning & Behavior*, **15**, 69-75.
- Pear, J. J. (1985). Spatiotemporal patterns of behavior produced by variable-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, **44**, 217-231.
- Pear, J. J. (1988). Behavioral stereotypy and the generalized matching equation. *Journal of the Experimental Analysis of Behavior*, **50**, 87-95.
- Pear, J. J., & Eldridge, G. D. (1984). The operant-responder distinction: Future directions. *Journal of the Experimental Analysis of Behavior*, **42**, 453-467.
- Pear, J. J., & Legris, J. A. (1987). Shaping by automated tracking of an arbitrary operant response. *Journal of the Experimental Analysis of Behavior*, **47**, 241-247.
- Peden, B. F., Browne, M. P., & Hearst, E. (1977). Persistent approaches to a signal for food despite food omission for approaching. *Journal of Experimental Psychology: Animal Behavior Processes*, **3**, 377-399.
- Timberlake, W., & Grant, D. L. (1975). Autoshaping in rats to the presentation of another rat predicting food. *Science*, **190**, 690-692.
- Timberlake, W., & Lucas, G. A. (1989). Behavior systems and learning: From misbehavior to general principles. In S. B. Klein & R. R. Mower (Eds.), *Contemporary learning theories: Instrumental conditioning theory and the impact of biological constraints on learning* (pp. 237-275). Hillsdale, NJ: Erlbaum.
- van Hest, A., van Haaren, F., Kop, P., & van der Schoot, F. (1986). Stimulus- and feeder-directed behavior in a long-box: Effect of fixed versus variable time schedules of food presentation. *Animal Learning & Behavior*, **14**, 168-172.
- Williams, D. R., & Williams, H. (1969). Auto-maintenance in the pigeon: Sustained pecking despite contingent non-reinforcement. *Journal of the Experimental Analysis of Behavior*, **12**, 511-520.

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